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Effects of light intensity within the canopy on maize lodging

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ABSTRACT

Close planting often increases the lodging rate of maize, but the cause is unclear. Close planting reduces light intensity within the canopy; therefore, we hypothesized that light intensity may be the main factor affecting maize lodging. To test this hypothesis, three field experiments involving plant density, shading and defoliation were designed to explore how the light environment in a maize canopy affects stalk strength formation and lodging rate. The results showed that close planting and artificial shading treatments both reduced light intensity in the lower canopy. This reduced the dry weight per unit length (DWUL) and rind penetration strength (RPS) of the third basal internode and increased the lodging rate. Removal of leaves 10–12 reduced the DWUL and RPS of the third internode and increased lodging rate. This showed that leaves 10–12 play a crucial role both in the formation of RPS of the third basal internode and in lodging resistance. Removal of either all or part of leaf 16 and above not only increased ptotosynthetic active radiation (PAR) at leaves 10–12 but also increased the DWUL and RPS of the third basal internode. This resulted in a decline in lodging. Therefore, we conclude that light intensity is an important factor affecting maize lodging at high plant density. Increasing light intensity at leaves 10–12 can enhance stalk strength and reduce lodging.

1. Introduction

Close planting is an important way to increase maize yield (Grassini et al., 2011; Chen et al., 2012; Ittersum and Cassman, 2013). However, high plant density often results in lodging, (Gou et al., 2007; Novacek et al., 2013). Surveys have shown that lodging reduces annual maize yields by approximately 30% (Zuber and Kang, 1978; Minami and Ujihara, 1991; Cheng et al., 2011). Therefore, maize lodging at high plant density is a major factor restricting future increases in maize yield. In addition to grain loss, lodging also results in greater harvest costs (Pellerin et al., 1990; Kamara et al., 2003). Maize lodging includes stalk lodging and root lodging. Plants are stalk lodged when broken at or below the ear-bearing node. Root lodging means that plants lean more than specific angle from vertical (Dudley, 1994; Novacek et al., 2013). Stalk lodging undermines the transport of water, nutrients and photosynthetic products. Therefore, stalk lodging causes greater grain losses than root lodged (Li et al., 2015). Previous studies showed that stalk lodging occurs most frequently at the third internode above the soil surface during grain filling (Zuber and Grogan, 1961; Martin and Russell, 1984; Gou et al., 2007). This is because stalk carbohydrates are transported to the ear at grain-filling. This reduces basal internode quality. At the same time, ear weight gradually increases, thus raising the maize plant's center of gravity. When maize is bent by the wind, the basal third internode acts as a lever which holds the plant upright (Yuan et al., 2002). In preliminary studies, we observed that stalk lodging (i.e., breakage) accounts for more than 60% of lodging in maize at high plant density (Gou et al., 2008, 2010). Therefore, improving stalk strength at the basal internode is an important goal for improving the lodging resistance of maize.

As we all know, close planting increases light competition among individual plants (Pagano and Maddonni, 2007). Generally, close planting of maize increases the leaf area index (LAI) and mutual shading among individual leaves. This shading significantly decreases photosynthetically active radiation (PAR) in the lower canopy from the mid-vegetative to early grain-filling stages (Tollenaar and Aguilera, 1992; Maddonni and Otegui, 2004). Moreover, photosynthetic capacity decreases when leaves are shaded or under weak light conditions because of changes in plant morphology, light capture, ptotosynthetic electron transport and levels of enzymes related to carbon assimilation (Li et al., 2014; Marchiori et al., 2014). Maize stalk strength formation is dependent on the

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Table 1
Precipitation, average air temperature, and maximum wind speed during the 2012 and 2013 growing seasons.

	Precipitation (mm)			Average temperature (°C)			Daily maximum wind speed (m s^{-1})		
Month	2012	2013	1981–2013 average	2012	2013	1981–2013 average	2012	2013	1981–2013 average
April	11.3	38.1	26.5	16.6	14.3	12.8	8.6	12.0	10.8
May	9.1	26.0	30.8	17.7	19.3	19.2	10.3	10.0	11.3
June	0.8	29.2	23.3	18.3	23.5	23.7	8.5	12	11.7
July	21.6	31.4	23.6	26.1	25.4	25.4	8.1	10	10.8
August	7.4	19.0	18.4	23.1	24.0	23.5	10.9	9.6	10.2
September	7.1	7.1	15.6	18.2	18.2	17.6	7.3	5.9	8.8
Total/average	57.3	150.8	138.1	20.8	20.8	20.4	9.0	9.9	10.5

accumulation and distribution of photosynthetic assimilates from leaves. Low light intensity caused by mutual shading may affect stalk strength through photosynthesis and related processes. However, it has not yet been clarified whether low light intensity under close planting affects stalk strength formation and maize lodging.

Maize stalk strength increases gradually as stalks develop. The matter and energy required for rapid morphogenesis and stalk strength formation are derived from leaves (Widstrom et al., 1988; Wang et al., 2013). The third internode and the leaf which is attached to the third internode (i.e., the eighth leaf) develop simultaneously (Fournier and Andrieu, 2000). At the beginning of stalk development, the eighth leaf is not fully expanded. Therefore, the material and energy required for the third internode elongation and thickening comes mainly from mature leaves below the eighth leaf. As the stalk develops, the eighth leaf matures. The contribution of eighth leaf and others to stalk strength of third internode is unknown. The question is more complex because low light intensity in densely planted maize also results in low photosynthetic rate and accelerated leaf aging (Borrás et al., 2003; Acciaresi et al., 2014). Therefore, we would like to clarify which maize leaves contribute most to stalk strength formation at the basal internode.

Based on the above analysis, the objective of this study was to determine whether and how canopy light intensity affects stalk strength formation and lodging in densely planted maize. The light intensity in maize canopies was altered by using different plant density, shading, and removal of leaves or parts of leaves from different canopy layers. The distribution of LAI and PAR within maize canopies and their relationship with stalk strength and lodging rate were investigated. This study will provide new insights about maize lodging under close planting. This information could be helpful for developing new maize cultivation practices and for helping crop breeders to develop lodging resistant maize cultivars.

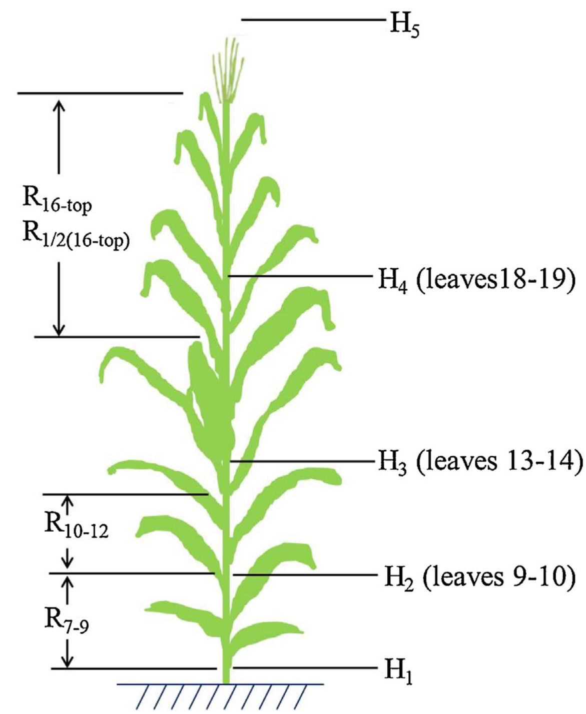

Fig. 1. Schematic diagram of the maize canopy layers.

2. Materials and methods

2.1. Experiment design and management

Xinjiang Province has an arid continental climate. Sunshine is abundant during the maize growing season; however, rainfall is low and irrigation is required. The field experiments were conducted at Shihezi Agricultural College, Shihezi University, Xinjiang, China (45°19′N, 86°03′E) in 2012 and 2013. Precipitation, air temperature and daily maximum wind speed were measured by an automatic weather station at the experiment site. Selected monthly weather conditions during the experiment and their historical averages are shown in Table 1. The soil at the site is classified as gray desert soil. Soil in 0–60 cm depth had the following characteristics: clay was 19.7%, silt is 33.1%, and sand is 40.5%. The soil bulk density is 1.32 g cm^{-3} in the 0–40 cm depth. Soil in 0–20 cm depth had the following characteristics: organic matter, 15.3 g kg^{-1}; total *N*, 1.1 g kg^{-1}; Olsen P, 19.1 mg kg^{-1}; and total *K*, 194 mg kg^{-1}.

Two maize cultivars were used in all three experiments. 'Zhongdan 909' is a lodging-resistant cultivar. 'Xinyu 41' is a commercial cultivar used by many farmers in the region. Leaf 14 was the ear leaf of both cultivars.

Experiment 1 consisted of three plant density treatments arranged in a randomized complete block: 4.5, 7.5, or 10.5 plants m^{-2} (respectively referred to as LD, MD, and HD). The MD is relatively common in northwest China. Experiment 1 was conducted in both 2012 and 2013.

Experiment 2 consisted of three shading treatments: unshaded (CK), 30% light exclusion (30%-S), and 60% light exclusion (60%-S). The 30%-S and 60%-S treatments were created by erecting a scaffold over each plot and then covering the scaffold with black polypropylene fabric so that the entire plot was shaded (Andrade et al., 2000; Jia et al., 2011). The weave of the fabric was different in 30%-S and 60%-S thus allowing different amounts of light to pass through. The shading treatments began 10 d before flowering. This was because 10 d before flowering is the most important time for the formation of maize stalk strength (Dudley, 1994; Gou et al., 2010). Furthermore, previous field surveys indicated that lodging in this region most frequently occurs at grain filling. Therefore, the shading treatment ended 40 d after flowering in order not to affect the occurrence of natural lodging. The plant density was 7.5 plants m^{-2}. Experiment 2 was conducted in 2013. The data were analyzed as a split-plot design with shading as the main plot factor and cultivar as the sub-plot factor.